Training femoral neck screw insertion skills to surgical trainees: computer-assisted surgery versus conventional fluoroscopic technique

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Abstract: BACKGROUND: Femoral neck fractures are among the most common orthopaedic injuries impacting the health care system. Surgical management of such fractures with cannulated screws is a commonly performed procedure. The acquisition of surgical skills necessary to perform this procedure typically involves learning on real patients with fluoroscopic guidance. This study attempts to determine if a novel computer-navigated training model improves the learning of this basic surgical skill. METHODS A multicenter, prospective, randomized, and controlled study was conducted using surgical trainees with no prior experience in surgically managing femoral neck fractures. After a training session, participants underwent a pretest by performing the surgical task (screw placement) on a simulated hip fracture using fluoroscopic guidance. Immediately after, participants were randomized into either undergoing a training session using conventional fluoroscopy or computer-based navigation. Immediate posttest, retention (4 weeks later), and transfer tests were performed. Performance during the tests was determined by radiographic analysis of hardware placement. RESULTS Screw placement by trainees was ultimately equal to the level of an expert surgeon with either training technique. Participants who trained with computer navigation took fewer attempts to position hardware and used less fluoroscopy time than those trained with fluoroscopy. When those trained with fluoroscopy used computer navigation at the transfer test, less fluoroscopy time and dosage was used. The concurrent augmented feedback provided by computer navigation did not affect the learning of this basic surgical skill in surgical novices. No compromise in learning occurred if the surgical novice trained with one type of technology and transferred to using the other. CONCLUSIONS The findings of this study suggest that computer navigation may be safely used to train surgical novices in a basic procedure. This model avoids using both live patients and harmful radiation without a compromise in the acquisition of a 3-dimensional technical skill.

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Training Femoral Neck Screw Insertion Skills to Surgical Trainees: Computer-Assisted Surgery Versus Conventional Fluoroscopic Technique

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Background: Femoral neck fractures are among the most common orthopaedic injuries impacting the health care system. Surgical management of such fractures with cannulated screws is a commonly performed procedure. The acquisition of surgical skills necessary to perform this procedure typically involves learning on real patients with fluoroscopic guidance. This study attempts to determine if a novel computer-navigated training model improves the learning of this basic surgical skill.

Methods: A multicenter, prospective, randomized, and controlled study was conducted using surgical trainees with no prior experience in surgically managing femoral neck fractures. After a training session, participants underwent a pretest by performing the surgical task (screw placement) on a simulated hip fracture using fluoroscopic guidance. Immediately after, participants were randomized into either undergoing a training session using conventional fluoroscopy or computer-based navigation. Immediate posttest, retention (4 weeks later), and transfer tests were performed. Performance during the tests was determined by radiographic analysis of hardware placement.

Results: Screw placement by trainees was ultimately equal to the level of an expert surgeon with either training technique. Participants who trained with computer navigation took fewer attempts to position hardware and used less fluoroscopy time than those trained with fluoroscopy. When those trained with fluoroscopy used computer navigation at the transfer test, less fluoroscopy time and dosage was used. The concurrent augmented feedback provided by computer navigation did not affect the learning of this basic surgical skill in surgical novices. No compromise in learning occurred if the surgical novice trained with one type of technology and transferred to using the other.

Conclusions: The findings of this study suggest that computer navigation may be safely used to train surgical novices in a basic procedure. This model avoids using both live patients and harmful radiation without a compromise in the acquisition of a 3-dimensional technical skill.

Key Words: computer navigation, surgical trainees, surgical skills, hip fracture

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INTRODUCTION

Femoral neck fractures are among the most common orthopaedic injuries that impact the health care system, costing over 12 billion dollars annually in the United States alone.[1] The surgical management of such fractures with cannulated screws is among one of the most common orthopaedic procedures performed.[2] Proper surgical technique in obtaining appropriate guidewire and hardware placement is known to be one of the most important factors in predicting outcome.[3,4]

The acquisition of the surgical skills necessary to perform this task is mandatory during the residency training process and typically involves learning on real patients with fluoroscopic guidance. Recent publications involving experienced orthopaedic surgeons have shown that when compared with conventional fluoroscopic guided techniques, computer-assisted fluoroscopic techniques provide significantly more accurate and precise placement of the guidewires and cannulated screws, with fewer drill tracks through the femur and less exposure to ionizing radiation.[5–7] In addition, after using computer navigation in the operating room, experienced orthopaedic surgeons demonstrate improved accuracy in free-hand component placement during subsequent procedures performed without computer navigation.[8]

Despite its success with expert surgeons, a number of motor learning studies have demonstrated that while the concurrent augmented feedback provided by technology such as computer navigation enhances performance during practice in trainees, it does not contribute to learning, as measured on delayed retention or transfer tests.[9–12] This is due to the learner either developing a dependence on the continuous additional feedback provided from extrinsic cues during the learning process (guidance hypothesis) or due to the learner deferring to the more readily available or interpretable

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extrinsic feedback over intrinsic feedback (attentional processes hypothesis).[13] It has been suggested that the concurrent augmented feedback provided by technology such as computer navigation needs to be appropriately diminished over time to avoid the development of learner dependence.[14]

This study attempted to determine if the form of feedback provided by computer navigation affected the learning of the basic orthopaedic surgical task of the placement of hardware across a femoral neck fracture in the surgical trainee. It was hypothesized that (1) computer-based navigation would not compromise the learning of hardware placement in the surgical trainee and (2) that those trained with computer navigation would be able to transfer their skills in effectively performing the task with conventional fluoroscopic guidance.

MATERIALS AND METHODS

A multicenter, prospective, randomized, controlled study was conducted. Ethics approval was obtained from the Research Ethics Board at the University of Toronto, Toronto, Ontario, Canada and Duke University, Durham, NC. Fifty-two senior medical students or first-year surgical residents (39 from the University of Toronto and 13 from Duke University) who had not yet performed the surgical procedure of internal fixation of a femoral neck fracture were recruited to participate. All participants gave informed consent to participate in the study.

The primary outcome measure for the study was placement of the hardware in the femoral head; secondary outcome measures included number of attempts taken to perform the task, number of times the subchondral bone of the femoral head was penetrated, the total radiation time and dosage during the procedure, and the total time taken to perform the procedure.

Power analysis indicated that a minimum of 17 participants in each group were needed to provide 80% power to detect clinically significant differences in screw position in the femoral neck. This was based on an earlier study by Liebergall et al[6] who showed that the difference in angle deviation of screws was about 4 degrees between the navigational and conventional group. This difference yields an effect size larger than 1 (Cohen d) for a 2-tailed Student *t* test. Therefore, a minimum of 17 per sample for a power of 80% and significance of 0.05 was required. Power analysis was done using a power analysis calculator (CenterSpace Software, Corvallis, OR).

A custom-designed left proximal femur model (Sawbones; Pacific Research Laboratories, Vashon, WA) was affixed in the supine position to a rigid mounting device that placed the model at the same height that is used during surgical fixation of a fractured hip. A surgical drape was then placed over the construct to prevent the study participant from using visual cues to determine the exact location for hardware placement. As the proximal femur model was not osteotomized, it simulated an undisplaced femoral neck fracture requiring internal fixation. At the University of Toronto, fluoroscopic images were taken with a Philips C-arm and fluoroscopy screen (Philips, Markham, ON), while at Duke University, a Ziehm C-arm and fluoroscopy screen (Ziehm, Orlando, FL) was used. Computer navigation was provided by a BrainLab system (Brainlab, Westchester, IL), which was linked to an infrared camera under stable tripod. Passive arrays were attached to a Shantz pin in the greater trochanter of the proximal femur model. The proximal femur was registered with standard anteroposterior and lateral fluoroscopic images taken by a certified radiology technician.

After viewing an instructional video on the principles of how 3 cannulated screws are placed across an undisplaced femoral neck fracture using both fluoroscopic and computer navigation guidance, all participants underwent a pretest by performing the surgical task of placing the three 2.8-mm guide wires (Synthes, Westchester, PA) in the model under fluoroscopic guidance. To minimize time taken to perform the procedure, participants did not insert any cannulated screws.

Immediately after the pretest, 27 participants (20 from Toronto, 7 from Duke) were randomly assigned into the conventional fluoroscopy-guided technique, whereas the remaining 25 participants (19 from Toronto, 6 from Duke) were assigned to the computer-based navigation technique. A 30-minute training session then followed and involved viewing the instructional video once again (approximately 10 minutes) and practicing with an expert instructor (approximately 20 minutes). Immediately upon completion of the training session, each participant performed the surgical task on the simulated hip fracture—this comprised the immediate posttest.

Four weeks later, the participants returned to perform a retention test of performance using the technique they were originally trained with. A transfer test then followed—each group of students repeated the surgical task but instead used the other technique to guide them (ie, those trained with the conventional fluoroscopy-guided technique used the computer-based navigation technique and vice versa).

It is important to recognize that the motor learning literature provides a very clear distinction between training and learning.[15] Training or practice changes in performance are temporary and can be influenced by factors such as motivation or fatigue or the guidance effects of immediate feedback. In contrast, true learning can only be evaluated after a rest interval and with all training groups being exposed to a common retention or transfer condition. This is termed the transfer design and is the design that was adopted in the present study.

Performance during the pretest, posttest, retention and transfer tests was determined by radiographic analysis of hardware placement. On standardized anteroposterior and lateral radiographs of the hip, the distance of the tip of the guidewires to the subchondral bone of the femoral head, guidewire parallelism, and the distance of the guidewire insertion point from lesser trochanter was measured. Secondary outcome parameters included (1) the total number of attempts required to perform the procedure, (2) the number of times the subchondral bone of the femoral head was penetrated, (3) the total radiation exposure during the procedure (as measured from the fluoroscopy unit), (4) the total radiation time required to perform the procedure (as measured from the fluoroscopy unit), and (5) the total time taken to perform the procedure.

For all participants, standard anteroposterior and lateral fluoroscopic images were taken at the end of each task by a certified radiology technician. The fluoroscopic images were then digitally transferred as DICOM (Digital Imaging and Communications in Medicine) files and measured by a single nonblinded evaluator in their original format using compatible software (Sante DICOM Viewer FREE v2.0, Santesoft, Athens, Greece). Each radiograph was calibrated according to a 15-mm-diameter ball bearing visible in the bone model image.

Parallelism was measured as an "Average Screw Deviation" as described in a previous study.[4] The shaft guidewire angle (α), defined as the angle between the femoral shaft axis and the axis of the wire, was measured in degrees, for each guidewire. The average difference $((|\alpha 1 - \alpha 2| + |\alpha 1 - \alpha 3| + |\alpha 2 - \alpha 3|)/3)$ between the 3 angles of the guidewires was calculated and recorded as "parallelism." Only the anteroposterior images were used to determine parallelism.

The distance from the guidewire tip to subchondral bone was measured directly as the shortest distance in millimeters from the tip of the wire to the outer border of the femoral head along the axis of the wire. For each wire (anterior, posterior, and inferior), the distance in anteroposterior and lateral views was compared and the smallest value was recorded. Finally, the average of the determined values of each wire was calculated and defined as the "distance from subchondral bone."

All dependent variables were analyzed using separate repeated measures analysis of variance models. Each model looked at the effect of group (conventional, computer assisted), time of test (pretest, posttest, and transfer test), as well as the interaction between group and time. For analysis of variance effects significant at $P < 0.05$, pairwise comparisons of means were carried out using Tukey's test. All analyses were carried out using SAS Version 9.1 (SAS Institute, Cary, NC).

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RESULTS

An analysis of the 2 randomized study groups did not demonstrate any statistically significant difference in the pretest with respect to all measured variables (Figs.1–4).

With regard to the primary outcome, distance of tip of guidewire to subchondral bone, all participants improved their accuracy of hardware placement in posttest ($P < 0.001$) (Fig. 1). This skill was retained at the same level at retention and transfer testing. There was no statistically significant difference between groups at any point.

No significant change was seen in guidewire parallelism at any time point. The only significant finding for the outcome, total time to perform the procedure, involved the

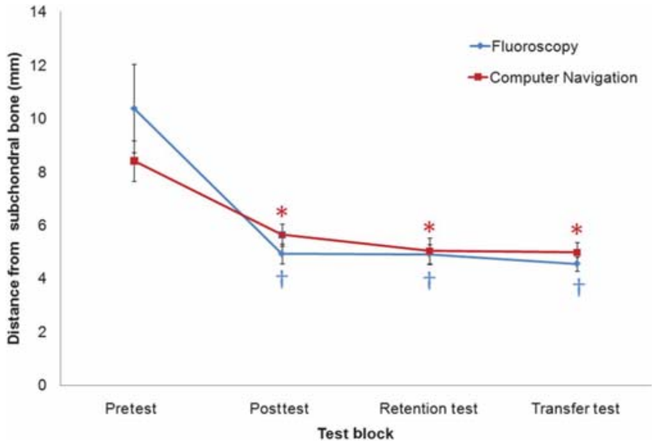

FIGURE 1. Distance from guidewire tip to subchondral bone. *Denotes significant improvement from pretest in group trained with computer navigation; †denotes significant improvement from pretest in group trained with fluoroscopy.

group trained with computer navigation. When this group transferred over to using fluoroscopy, the total time to perform the procedure was significantly decreased as compared with the pretest, posttest, and retention tests.

For the outcome, number of attempts required to perform the procedure, the group that underwent computer navigation training showed a significantly reduced number of attempts at posttest ($P = 0.0003$) (Fig. 2). This skill level was retained at retention test and transfer testing. Participants that trained with fluoroscopy took fewer attempts ($P < 0.05$) to position hardware only when they used computer navigation during transfer testing.

The total radiation time and dosage required to perform the procedure diminished significantly in the computer navigation group from pre- to posttest ($P < 0.0001$ and $P < 0.05$, respectively) (Figs. 3, 4). This skill level remained unchanged in the retention test. Participants who trained with fluoroscopy did not demonstrate a change in total radiation time or dosage from pre- to posttest to retention test. During transfer testing, participants who trained with fluoroscopy used less radiation time ($P < 0.0001$) and radiation dose ($P = 0.007$) when they subsequently completed the task using computer navigation. Participants who trained with computer navigation used more radiation time ($P = 0.0001$) and radiation dose ($P < 0.02$) when completing the task using fluoroscopy.

Neither of the groups showed statistically significant changes in the number of times the subchondral bone of the femoral head was penetrated at any time point in the study. There was no difference between training groups either.

DISCUSSION

The purpose of this study was to determine the effect of computer navigation on the learning of a basic orthopaedic surgical procedure in the medical trainee, performing internal fixation of a femoral neck fracture. This study showed that the primary outcome measure, hardware positioning, improved

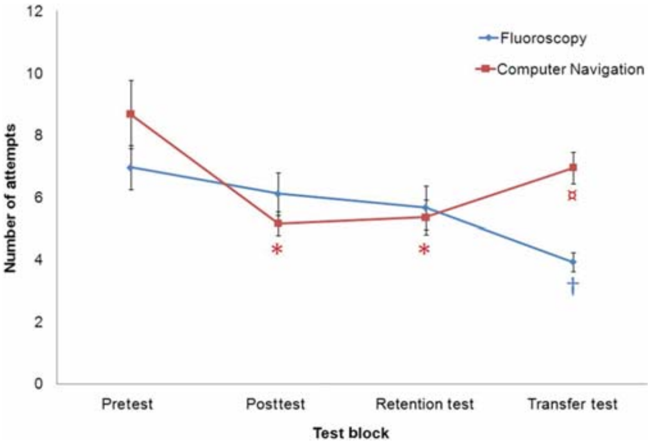

FIGURE 2. Total number of attempts. *Denotes significant improvement from pretest in group trained with computer navigation; †denotes significant improvement from pretest, posttest, and retention test in group trained with fluoroscopy; and ¤denotes significant increase in the number of attempts from posttest in group trained with computer navigation.

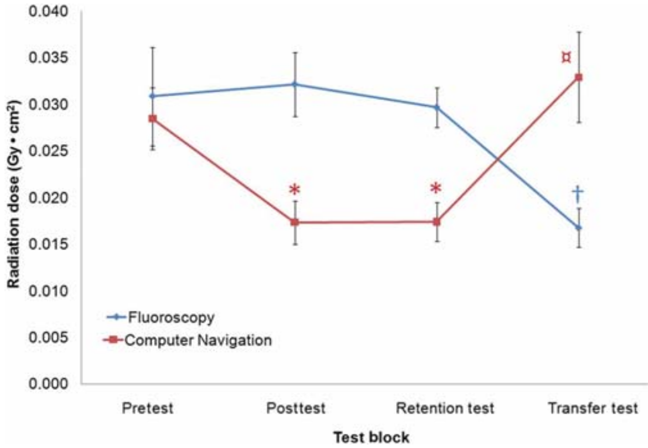

FIGURE 4. Radiation dose. *Denotes significant reduction in radiation time from pretest in group trained with computer navigation; †denotes significant reduction in radiation time from pretest, posttest, and retention test in group trained with fluoroscopy; ¤denotes significant increase in radiation time from posttest and retention test in group trained with computer navigation.

after the training session, whether the surgical novices used fluoroscopy or computer navigation. The positioning of hardware reached that of expert surgeons, as each group was able to place the guidewire within the goal of 5 mm of subchondral bone. The participants maintained this level of skill during retention and transfer testing.

There have been few studies that have examined how computer-assisted surgery affects the skills of surgical trainees when learning how to perform routine orthopaedic surgical procedures.[15–20] Like ours, all of the prior studies have shown that when medical trainees use computer navigation, component positioning equals that of expert surgeons; however, the longer term retention of this skill was not evaluated. In addition, none of the studies presented evidence of whether they were sufficiently powered to determine their primary outcome, mentioned how the type of training their participants underwent at the beginning of the study was standardized, or mentioned participant performance on a retention test of performance.

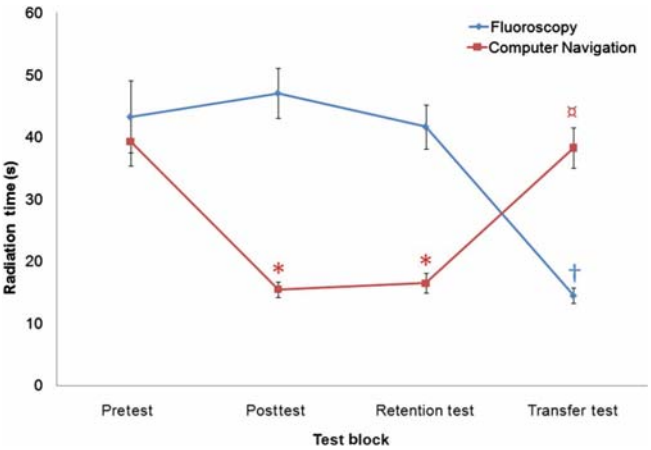

FIGURE 3. Radiation time. *Denotes significant reduction in radiation time from pretest in group trained with computer navigation; †denotes significant reduction in radiation time from pretest, posttest, and retention test in group trained with fluoroscopy; and ¤denotes significant increase in radiation time from posttest and retention test in group trained with computer navigation.

Some of these limitations were overcome by a well-designed study by Gofton et al,[19] who compared computer navigation–guided training to conventional training in the placement of a total hip arthroplasty acetabular cup in surgical trainees. The concurrent augmented feedback provided by computer navigation was found to improve early performance and lead to equivalent learning in component positioning during the immediate delayed retention and transfer tests.

The placement of 3 cannulated screws across a reduced femoral neck fracture provides a different technical challenge from implanting an acetabular cup during a total hip arthroplasty and may be considered to be a more complex task. While the ideal position of a total hip arthroplasty cup must be determined in the axial and coronal planes, the 3 guidewires and subsequent screws used in femoral neck fracture fixation must (1) be placed parallel to each other in the coronal and sagittal plane, (2) have their insertion point located proximal to the lesser trochanter, (3) be in the form of an inverted triangle, (4) be within 5 mm of the subchondral bone of the femoral head, and (5) have appropriate spread between the screws.

What also makes this procedure more complex than total hip arthroplasty acetabular component positioning is that, in addition to responding to cues obtained from the operative site, the surgeon must respond to cues provided from the fluoroscopy unit that is used to guide hardware placement. The continuous extrinsic feedback visual cues shown on the fluoroscopy monitor screen provide immediate knowledge of hardware placement (knowledge of results), allowing the surgeon to adjust hardware placement at any time during the procedure.

In the present study, neither guidewire parallelism nor the number of times the subchondral bone of the femoral head was penetrated, improved in either group during the study. At best, the group trained with both fluoroscopy and computer navigation achieved parallelism within 3 degrees of what expert surgeons achieve (ie, 0 degrees).[6] Although it is recommended that the 3 guidewires/screws should be inserted in a parallel manner, the literature does not provide data that would support that suggestion. In 2 clinical studies, no relationship between the angulation of the screws and the occurrence of fracture nonunion was found.[21,22] The increased parallelism values seen in the participants in this study may not be of clinical relevance.

Both groups of participants penetrated the subchondral bone of the femoral head at a mean of up to 2 times. Although no published literature exists on this component of hip fracture fixation, it is reasonable to assume that most experts rarely penetrate the subchondral bone of the femoral head when performing this procedure. Why no improvement was seen with these parameters in any group may be because of a weakness in the training module—it is possible that the participants' attention was focused more on other aspects of guidewire placement, that simply more practice is required, or learner exhaustion occurred, producing a ceiling effect.

In keeping with the literature on expert and novice surgeons,[16] this study found that participants trained with computer navigation minimized the number of attempts to place the hardware. In comparison to the pretest, an improvement was seen during the posttest and retention test, with no significant improvement between these times. The number of attempts was significantly increased in the transfer test (ie, when they transferred to using fluoroscopy) when compared with the posttest (ie, when they used navigation). In contrast, those trained with fluoroscopy did not show any decrease in attempts until they transfer tested with computer navigation. The decrease in attempts seen when computer navigation was used was likely because of the technological advantage inherent to computer navigation. As computer navigation provides information of the anticipated trajectory of hardware in bone in both the coronal and sagittal planes, adjustments can be made by the surgeon to ensure correct hardware positioning in both planes even before the hardware is introduced into bone.

The fact that those trained with computer navigation in this study used significantly less total radiation time and dosage after training is also in keeping with the literature.[5] Why those that trained with fluoroscopy did not minimize the total time and amount of radiation until they transferred over to using computer navigation may again be explained by the fact that the use of computer navigation alone provides an inherent advantage in these parameters. This is further supported by the fact that when those trained with computer navigation used fluoroscopy in the transfer test, the time and amount of radiation used significantly increased.

Although many publications have shown that expert surgeons generally use less time to perform navigated cases,[5–7] only one study has investigated the effect of computer navigation when used by experts to place cannulated screws in a simulated hip fracture model.[5] This particular study concluded that experts require a similar amount of time to place screws across the femoral neck whether they use navigation or not.[5] Although the present study did not have the participants place cannulated screws in bone, thus making a direct comparison to the data from the prior study difficult, the time taken by the novices to place the guidewires in the bone model in this study can be considered to be comparable to that taken by expert surgeons. The participants took approximately 16.6 ± 6.6 minutes to perform the procedure. No improvement in time occurred at any time point during the study for those trained with fluoroscopy but the group that trained with computer navigation did decrease their procedure time when they transferred to using fluoroscopy. This finding can be explained by the fact that training with computer navigation potentially gave the participants a better sense of where to place the hardware in 3-dimensional space; this skill was transferred even when fluoroscopy was used.

Basic motor theory suggests that while concurrent augmented feedback enhances the performance of novices during practice, it does not contribute to learning, as measured on delayed retention or transfer tests.[9–12] Despite the basic motor theory, Gofton et al[19] found that the augmented feedback provided by computer navigation in training surgical novices how to position a total hip arthroplasty acetabular cup did not compromise learning.

This study similarly observed that the concurrent augmented feedback provided by computer navigation did not compromise the learning of a new surgical task. Instead, it improved many aspects of task performance that were maintained at immediate and delayed retention testing and transfer testing. Not only was the primary outcome measure of hardware placement improved to a level exhibited by expert surgeons but so were the secondary outcome measures of decreased attempts taken to perform the procedure, decreased procedure time, and minimized total radiation dose and time.

The reason why we saw no improvement in the outcome parameters of guidewire parallelism or number of subchondral bone penetrations in either training group may be because of a number of factors. The functional task difficulty of the study may have been too high for this level of (novice) learner; although they were able to improve their skills in some outcome measures, they were unable to successfully learn other skills that were reflected in other outcome measures. In addition, learner exhaustion from the training video/expert instruction session may have occurred, causing a ceiling effect. It is possible that with more practice, the participants' skill would have improved in these parameters.

Should computer navigation be used in the training of basic surgical skills in surgical novices? The findings of this study suggest that computer navigation may be safely used to train surgical novices in this basic surgical procedure. Nevertheless, the task is complex and further studies are required to show how novices can learn to improve all aspects of performing this procedure to expert levels.

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